Temperature Preconditioning

Susan Lurie[1] and Joshua D. Klein[2]
[1]Department of Postharvest Science and [2]Department of Field Crops
Volcani Center, Bet-Dagan, Israel

Introduction: Temperature preconditioning of fruits and vegetables has been practiced for more than 70 yr, since Baker (1939; 1952) described heat treatments for disinfestation of fruit flies in citrus. There is renewed interest in high temperature as a postharvest treatment for control of both insect pests and fungal pathogens in fresh produce. In part, this is because of the deregistration of a number of compounds that have until recently been used for effective control of postharvest disorders. In addition, there is increased consumer demand for produce that has had minimal, or ideally no, chemical treatment.

Heat has fungicidal and well as insecticidal action, but heat regimes that are optimal for insect control may not be optimal for disease control; in some cases they may even be detrimental. A thermal treatment that is developed for fungus or insect control should not damage the commodity being treated.

In fact, in many cases high temperature manipulation before storage may have beneficial effects on the commodity treated. These benefits include slowing the ripening of climacteric fruit and vegetables, enhancing sweetness of produce by increasing the amount of sugars or decreasing acidity, and prevention of storage disorders such as superficial scald on apples and chilling injury on subtropical fruits and vegetables (Lurie, 1998).

Temperature conditioning before storage may also mean an incubation period spent at either ambient temperature of 16 to 25 °C (about 61 to 77 °F) or at a temperature below ambient, but above that which might produce chilling injury, ie., 5 to 12 °C (about 41 to 54 °F), depending on commodity. This type of temperature manipulation is often referred to as a a 'curing' period, and it is used with crops such as potatoes, onions and carrots. Its purpose is generally to enhance resistance of the commodity to pathogen invasion, although it may also enhance resistance to low temperature injury in citrus.

In this chapter we discuss temperature preconditioning treatments according to their purpose, ie., pathogen, insect or chilling injury control. Most of the methods listed here, however, are still experimental, and have yet to be accepted for routine commercial practice.

Commercial Treatments: The greatest number of temperature manipulations used commercially are based on high temperature treatments (vapor heat or hot forced-air) for insect disinfestation. Temperature regimes are developed specifically for each commodity and insect pest. The accepted procedures for produce entering the U.S. are described in the USDA-APHIS Plant Protection and Quarantine Treatment Manual, which is routinely updated (Animal and Plant Protection Service, 1998). The latest edition of the manual should be consulted for approved treatments for particular commodities or pests.

An example of commercial temperature conditioning for pest control is Mexican-grown mangos, which may be infested with a variety of fruit fly larvae or eggs. Officially authorized treatments are high-temperature, forced-air (HAT) or a hot water dip treatment (HWT) before storage and shipment. In HAT, fruit are heated until their center reaches 48 °C (118 °F). HWT conditions depend on fruit size and vary from 45 to 90 min in water, where the fruit interior reaches 46.1 °C (115 °F).

Vapor heat (VHT) differs from high-temperature, forced-air in that moisture accumulates on the surface of the fruit. The water droplets transfer heat more efficiently than air, allowing the fruit to heat quickly; but there may also be increased physical injury to the fruit. Papayas grown in Hawaii are vapor heat-treated before export to Japan.

Citrus can be disinfested by HAT at 44 °C (111 °F) for 100 min, with an additional 90 min spent raising the temperature to 44°C. The usual disinfestation method, however, is to hold the fruit at low temperature of 0 to 2.2 °C (32 to 36 °F) for 10 to 16 days, before raising the temperature to the normal storage temperature of 6 to 11°C (43 to 52 °F), depending on cultivar. Since citrus is sensitive to chilling, fruit are generally held at 20 °C (68 °F) or 16 °C (61 °F) for 3 to 5 days before placing at low temperature. This curing treatment decreases fruit susceptibility to chilling injury resulting from the subsequent disinfestation treatment.

Insect Disinfestation: The development and implementation of heat treatments for insect disinfestation have been reviewed thoroughly (Couey, 1989; Paull, 1993). The list below includes treatment regimes that have been reported in the past 10 years (Table 1). More than half the treatments are designed to kill fruit fly eggs or larvae, since their presence requires strict quarantine in most fruit-importing countries. The most recently developed methods include heat treatments in combination with low O_2 or high CO_2 atmospheres.

Antifungal Treatments: Curing is used commercially to increase resistance to pathogen invasion. Potatoes are cured at 12 °C (54 °F) for 10 to 12 days before storage at 4 to 9 °C (39 to 48 °F), depending on cultivar and whether they are designated for industry or home consumption. Sweet potatoes are also cured at 30 °C (86 °F) for 5 days, before storage at 12 °C (54 °F). In both cases the curing period allows for wound healing and deposition of cell wall material to create a physical barrier to pathogens. Kiwifruit also benefit from a curing period. If held at 10 °C (50 °F) before storage at low temperature, they develop fewer rots after storage. Onions can be stored longer if held at 28 °C (82 °F) for 3 days before storage.

The two commercial applications of high temperature antifungal treatments are HWT for papayas (Akamine and Arisumi, 1953), which has been used for almost 50 yr, and a hot water brush treatment that was introduced fairly recently (Fallik, 1996a, 1999; Prusky et al., 1997). The brush system is in use on packing lines for export of corn, mangos, peppers and some citrus from Israel. The machine sprays hot water at 50 to 65 °C (122 to 149 °F) on produce as it moves along on brush rollers. The major benefit appears to be removal of spores and dirt, although hot water combined with brushing also causes surface cracks to be filled in by the natural wax of the commodity, as well as eliciting resistance to pathogens in some cases.

The state of temperature conditioning treatments against fungal pathogens was reviewed by Barkai-Golan and Phillips (1991) and Coates and Johnson (1993). The majority of the regimes listed in Table 2 were developed in the past 5 years. Dips in hot fungicide solution have been used since the 1950s for pathogen control. As various fungicides lose their registration or as pathogens develop resistance, there is increased interest in heat-treating produce in combination with compounds that are generally recognized as safe (GRAS), such as $CaCl_2$ or sodium carbonate (Table 2).

Physiological Benefits of Conditioning Treatments: Most thermal treatments have been developed as lethal regimes for insects or fungi. Some of these regimes, however, also have prophylactic effects against physiological disorders such as chilling injury (CI). Prevention of CI allows the commodity to be stored longer at lower temperatures, which in turn permits export in ships rather than more costly air-freight. In addition, a pre-shipping heat treatment can allow for low temperature disinfestations of commodities such as citrus, by improving the resistance of fruit to CI generally incurred during this treatment.

Other heat treatments have been developed specifically to maintain postharvest quality, such as increased firmness of apples or decreased yellowing of broccoli, or to protect against other abiotic stresses, such as irradiation disinfestation treatments (Table 3). The physiological mechanisms of these treatments was previously reviewed by Lurie (1998).

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Table 1.

Insect	Latin name	Fruit	Regime	Temperature/Time	Reference
Fruit flies					
Caribbean fruit fly	*Anastrepha suspensa*	grapefruit	HAT*		Sharp & Gould '94
		mango	HAT	51.5 °/125 min	Miller et al. '91
		orange	HAT		Sharp & McGuire '96
Mediterranean fruit fly	*Ceratitis capitata*	avocado	HAT	40 °/24 h	Jang '96
		mango	VHT	47 °/15 min	Heather et al. '97
		papaya	HAT	47.2 ° at pulp for 3.5 h	Armstrong et al. '95
Melon fruit fly	*Dacus cucurbitae* *Bactrocera cucurbitae*	avocado	HAT	40 °/24 h	Jang '96
		cucumber	HAT then HWT	32.5 °/24 h then 45-46 °/50-60 min	Chan & Linse '89
		papaya	HAT	47.2 ° at pulp for 3.5 h	Armstrong et al. '95
		zucchini	VHT		Jacobi et al. '96
Mexican fruit fly	*Anastrepha ludens* *Bactrocera cucumis*	grapefruit	HAT & CA	44 °/2 h in 1% O_2	Shellie et al. '97
		zucchini	VHT	45 °/30 min	Jacobi et al. '96
Oriental fruit fly	*Dacus dorsalis* *Bactrocera dorsalis*	cucumber	HAT then HWT	32.5 °/24 h then 45-46 °/50-60 min	Chan & Linse '89
		papaya	HAT	47.2 ° at pulp for 3.5 h	Armstrong et al. '95
Papaya fruit fly	*Bactrocera payapae*	mango	VHT	47 °/15 min	Heather et al '97
Queensland fruit fly	*Bactrocera tyroni*	avocado	HWT & benomyl	46 °C/3 min then 1 °/7 days	Jessup '94
		litchi	VHT	45 °/30 min	Jacobi et al. '93
		mango	VHT	46.5 °/10 min	Heather et al. '97 Jacobi et al. '95
			HWT then VHT	53 °C/15 min then 47°C/15 min	Jacobi & Giles '97
Other Insects					
Coddling moth	*Cydia pomonella*	apple	HAT or VHT	44 °/120 min then 0 °/4 weeks	Neven et al. '96
		cherry	HAT & CA	47 °/44 min in 1% O_2; 15% CO_2	Neven & Mitcham '96 Neven & Drake '00
		pear	HAT or VHT	44 °/120 min then 0°/4 weeks	Neven et al. '96
			HAT & CA	30 °/ 30 h in 0.3% O_2	Chervin et al. '97
Fuller's rose beetle	*Asynonychus godmani*	lemon	HWT	52 °/8 min	Soderstrom et al. '93
Leafroller	*Cnephasia jactatana* *Ctenopseustis obliquana*	apple	HAT & CA	40 °/10 h in 0.4% O_2 45 °/5 h in 0.4% O_2	Whiting et al. '99
		kiwifruit	HAT & CA	40 °/5-7 h in 0.4% O_2 40 °/6 h in 2% O_2; 5% CO_2	Whiting et al '97 Hoy & Whiting '98
Light brown apple moth	*Epiphyas postvittana*	apple	HAT & CA	40 °/17-20 h in 1.2% O_2; 1% CO_2	Lay-Yee et al. '97 Dentener et al. '00
			HWT & ethanol	45 °/13 min in 50% ethanol	Hoy & Whiting '98
		kiwifruit	HAT & CA		
		pear	HAT & CA	30 °/30 h in 0.3% O_2	Chervin et al. '97
Longtailed mealybug	*Pseudococcus longispinus*	persimmon	HWT	48 °/26 min or 50 °/22 min	Lester et al. '95
			HAT		Dentener et al. '96,'97
New Zealand flower thrips	*Thrips obscuratus*	apricot nectarine peach	HWT	48 °/3 min then 50 °/2 min	McLaren et al. '97
Obscure mealybug	*Pseudococcus affinis*	apple	HAT & CA	40 °/10 h in 0.4% O_2 45 °/5 h in 0.4% O_2	Whiting & Hoy '97
Oriental fruit moth	*Grapholita molesta*	pear	HAT & CA	30 °/30 h in 0.3% O_2	Chervin et al. '97
Two spotted spider mite	*Tetranychus urticae*	apples	HWT & ethanol	45 °/13 min in 50% ethanol	Dentener et al. '98
		kiwifruit	HAT & CA	44 °/211 min	Lay-Yee & Whiting '96
		perimmon	HWT	47 °/67 min	Lester et al. '97
White peach scale	*Pseudaulacaspis pentagona*	papaya	VHT	47.2 °/4 h	Follet & Gabbard '99

Table 2. Thermal treatment of horticultural commodities for eradication of and protection from fungal pathogens.

Fungus	Common name	Crop	Regime	Temperature/Time	Reference
Alternaria alternata	Black spot	carrot	HWB	100 °/3 sec	Afek et al. '99
		mango	HWB	60-70 °/15-20 sec	Prusky et al. '99
	Black mold	pepper	HWT	50 °/3 min	Fallik et al. '96b
Botrytis cinerea	Grey mold	Apple	HAT & $CaCl_2$	38 °/4 days and $CaCl_2$ dip	Klein et al. '97
		pepper	HWT	50 °/3 min	Fallik et al. '96b
		strawberry	HWT	45 °/15 min	Garcia et al. '96
		tomato	HWT	50 °/2 min	Barkai-Golan et al. '93
			HAT	38 °/2 days	Fallik et al. '93
Botryodiplodia theobromae	Stem and surface rots	papaya	HAT	49 °/20 min 32 °/30 min then 49 °/20 min	Nishijima et al. '92
Chalara paradoxa	Crown rot	banana	HWT	45 °/20 min or 50 °/10 min	Reyes et al. '98
Colletotrichum gloeosporioides	Anthracnose	mango	VHT	46-48 °/24 sec - 8 min	Coates et al. '93
			HWT		McGuire '91
			HAT	51.5 °/125 min	Miller et al. '91
Diplodia natalensis	Stem end rot	mango	HAT	51.5 °/125 min	Miller et al. '91
			HWT		McGuire '91
Mycospharella spp.	Stem and surface rots	papaya	HAT	49 °/20 min 42 °/30 min then 49°/20 min	Nishijima et al. '92
Penicillium digitatum	Green mold	grapefruit	HAT	46 °/6 h	Shellie '98
			HWB	59-62 °/15 sec	Porat et al. '00
		lemon	HAT	36 °/3 days	Kim et al. '91
			HWT & Na_2CO_3	45 °/150 sec + 2% Na_2CO_3	Smilanick et al. '97
		orange	HWT	53 °/3 min	Schirra et al. '97
			HWT & Na_2CO_3	41-43 °/1-2 min + 6% Na_2CO_3	Smilanick et al. '97
Penicillium expansum	Blue mold	Apple	HAT & $CaCl_2$	38 °/4 days + 4% $CaCl_2$	Sams et al. '93
			HAT	38°/4 days	Fallik et al. '96c
Penicillium italicum	Blue mold	cactus pear	HAT or HWT	38 °/24 h or 55 °/5 min	Schirra et al. '96
Penicillium spp.		lemon	HWT & imazalil	50 °/3 min + imazalil	Schirra et al. '97
Rhizopus stolonifer		tomato	HWT	50 °/2 min	Barkai-Golan et al. '93

Table 3. Physiological benefits of thermal treatments for horticultural crops.

1. Chilling injury

Crop	**Phenomenon/Appearance**	**Regime**	**Temperature/Time**	**Reference**
Apple	scald	HAT*	38 °/4 days or 42 °/2 days	Lurie et al. '90
Avocado	skin browning	HAT then	38 °/3-10 h then	Woolf et al. '95
	internal browning,	HWT	40 °/30 min	Florissen et al. '96
	pitting		38 °/60 min	Woolf et al. '97
		HWT		
Cactus pear	rind pitting, brown staining	HAT or HWT	38 °/24 h or 55 °/5 min	Schirra et al. '96
Citrus	rind pitting	HAT	34-36 °/48-72 h	Ben -Yehoshua et al. '87
				Gonzalez-Aguilare et al. '98
		HWT	50-54 °/3 min	Schirra & D'hallewin '97
			53 °/2-3 min	Rodov et al. '95
		HWB	59-62 °/15-30 sec	Porat et al. '99
Mango	pitting	HAT	38 °/2 days	McCollum et al. '93
			54 °/20 min	Jacobi et al. '95
Persimmon	gel formation	HWT	47 °/90-120 min; 50 °/30-45 min; 52 °/20-30 min	Lay-Yee et al. '97
		HAT		Woolf et al. '97
Green pepper	pitting	HAT	40 °/20 h	Mencarelli et al. '93
Cucumber	pitting	HWT	42 °/30 min	McCullum et al. '95
Tomato	pitting	HAT	38 °/2-3 days	Lurie & Klein '91
		HWT	48 °/2 min	Lurie et al. '97
			42 °/60 min	McDonald et al. '98, '99
Zucchini	pitting	HWT	42 °/30 min	Wang '94

2. Improved postharvest quality

Commodity	**Parameter/attribute**	**Regime**	**Temperature/Time**	**Reference**
Apple	increased firmness	HAT	38 °4 days; 42 °/2 days	Klein & Lurie '92
Asparagus	inhibited curvature	HWT	47.5 °/2-5 min	Paull & Chen '99
Broccoli	decreased yellowing	HWT	50 °/2 min	Forney '95
			45 °/10 min; 47 °/7.5 min	Tian et al. '96, '97
Collard	decreased yellowing	HAT	45 °/30 min	Wang '98
Green onions	inhibited elongation	HWT	55 °/2 min	Hong et al. '00
Guava	decreased softening and yellowing	HWT	46 °/35 min	McGuire '97
Kale	decreased yellowing	HAT	40 °/60 min	Wang '98
Potato	inhibited sprouting	HWT		Rangann et al. '98